Comments on TOPEX High-Rate SSH Estimates in the Vicinity of the Corsica and Harvest Platform Verification Sites

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Introduction and Summary

At several TOPEX/Poseidon Science Working Team meetings, there have been reports of observations from a verification site at Ajaccio in Corsica which is overflown by pass 085 in each data cycle. The reports indicated that the TOPEX high-rate (10 per second) sea surface height (SSH) data showed unusual range oscillations or "ringing". To understand whether the ringing was a real problem, we at Wallops Flight Facility have examined some pass 085 data from nearly three dozen TOPEX cycles to try to understand the effect, and also to see if there appeared to be significant difference in the ringing between Side A and Side B tracking.

We have concluded that the ringing is a consequence of the "sigma0 bloom", a term we use to designate anomalously high apparent ocean surface radar backscattering. The sigma0 bloom is accompanied by a change in the shape of the radar mean return, and the altimeter-estimated range values will be contaminated at some level. The sigma0 blooms are more likely to occur at low wind speeds, and the relatively sheltered verification site in Corsica probably has ocean which has been subjected to low-fetch, low velocity winds. Data editing to remove sigma0 bloom contaminated data will remove much of the apparent ringing in Corsica verification passes; unfortunately the editing removes much of the data as well.

After completing our examination of TOPEX high-rate SSH data in the vicinity of the Corsica verification site, we looked at the high-rate SSH data for the Harvest platform off the California coast. The Harvest site is in the pass 043 ground track. For quick comparison, pass 043 was used from the same 35 TOPEX cycles for which we had studied pass 085. It was expected that the Harvest platform would have a higher fraction of good passes because the altimeter approaches the platform from over open ocean, whereas the Sardinia-to-Corsica passes come off land at Sardinia and traverse relatively shallow and protected water before going back overland at Corsica. In brief summary, there were relatively fewer problem passes at Harvest than at Corsica.

The remainder of this report consists of two sections. The first of these sections describes the investigation of the pass 085 data near the Corsica verification site. Then the second section describes the investigation of the pass 043 data near the Harvest platform, and compares the frequency of sigma0 bloom contamination in the Corsica and the Harvest vicinity.

Corsica Vicinity TOPEX Verification Passes

A French TOPEX/Poseidon verification site at Ajaccio in Corsica is overflown by pass 085 in each data cycle. Pass 085 travels roughly northeast going from Sardinia to Corsica in the Mediterranean, and Figure 1 shows the cycle 281 pass 085 ground track on a latitude *vs.* longitude plot which also shows the coastal outlines. Sardinia is the southern one of the two islands in the center of this figure, and Corsica is the northern one. Three different plot symbols

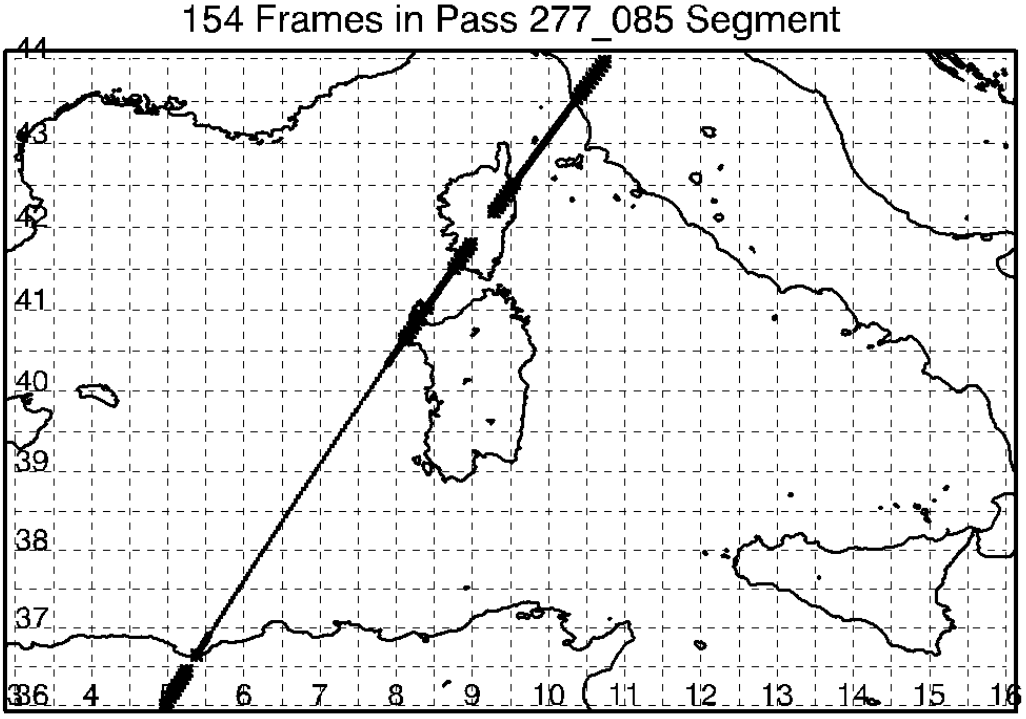
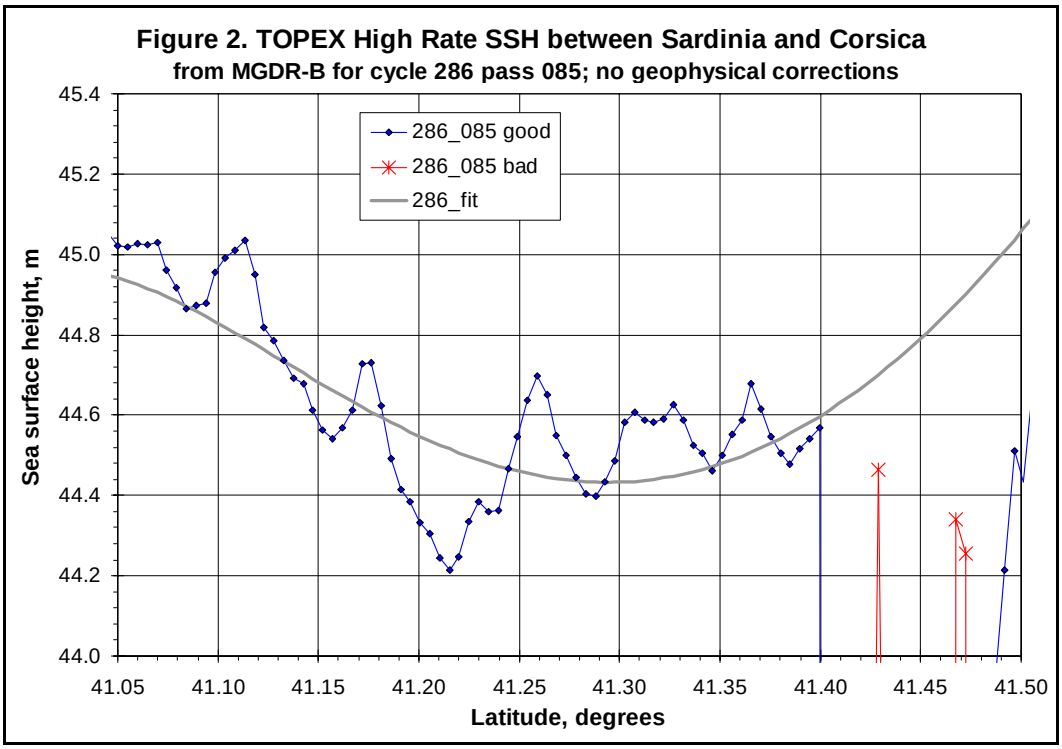


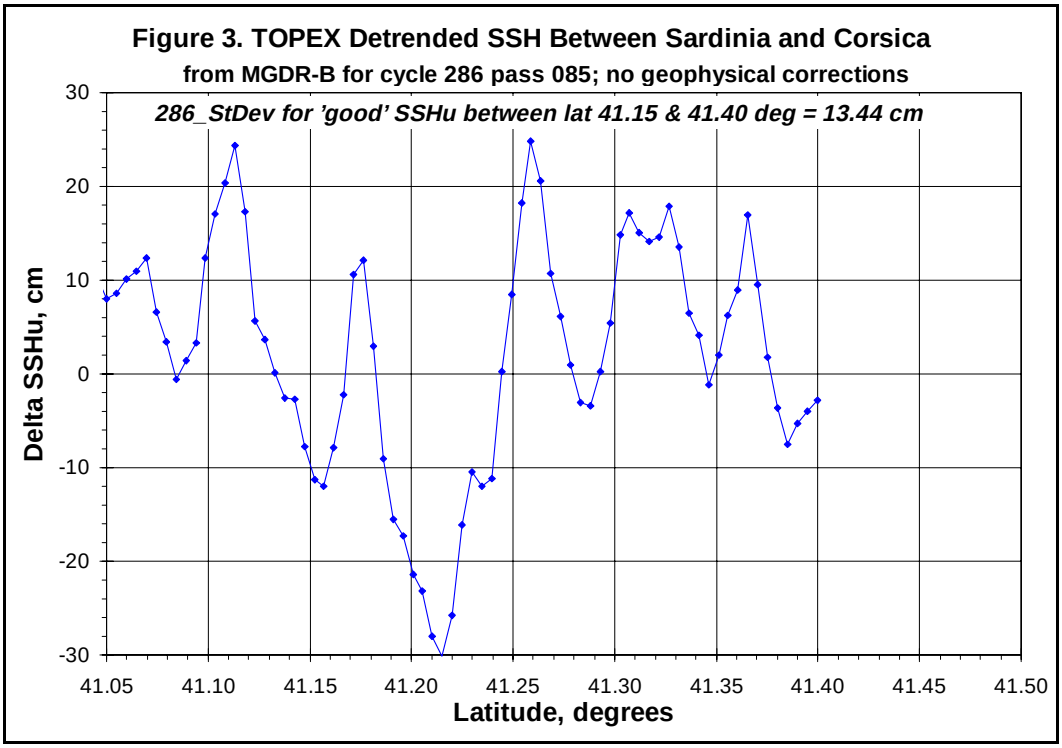
Figure 1. TOPEX Ground Track Over Sardinia and Corsica.

were used in this plot, with the symbol size being set by the LandWater flag (derived from bits 0 and 1 of the Geo_Bad_1 flag in the data). The widest symbol indicates overland data as at the northwest tip of Sardinia, at Corsica, and at the landfall at Italy at the upper end of the pass segment shown. The intermediate symbol width indicates shallow water as in the pass segment from Sardinia to Corsica and from Corsica to Italy. The smallest symbol indicates deep ocean as in the pass segment approaching Sardinia from the southwest. The plot was produced by IDL version 5.4 using continental outlines from IDL's optional high-resolution database.

A local on-line set of MGDR-B data was used in this study because of its convenience and ease of access. IDL was used to read the MGDR-B, select the data region of interest, and to form the high-rate (~ 10/sec) SSH and time values together with interpolated longitude and latitude values. Figure 2 shows the high-rate SSH *vs*. latitude in the region between Sardinia and Corsica for cycle 286. The SSH values plotted in Figure 2 (and subsequent figures) are **not** corrected for



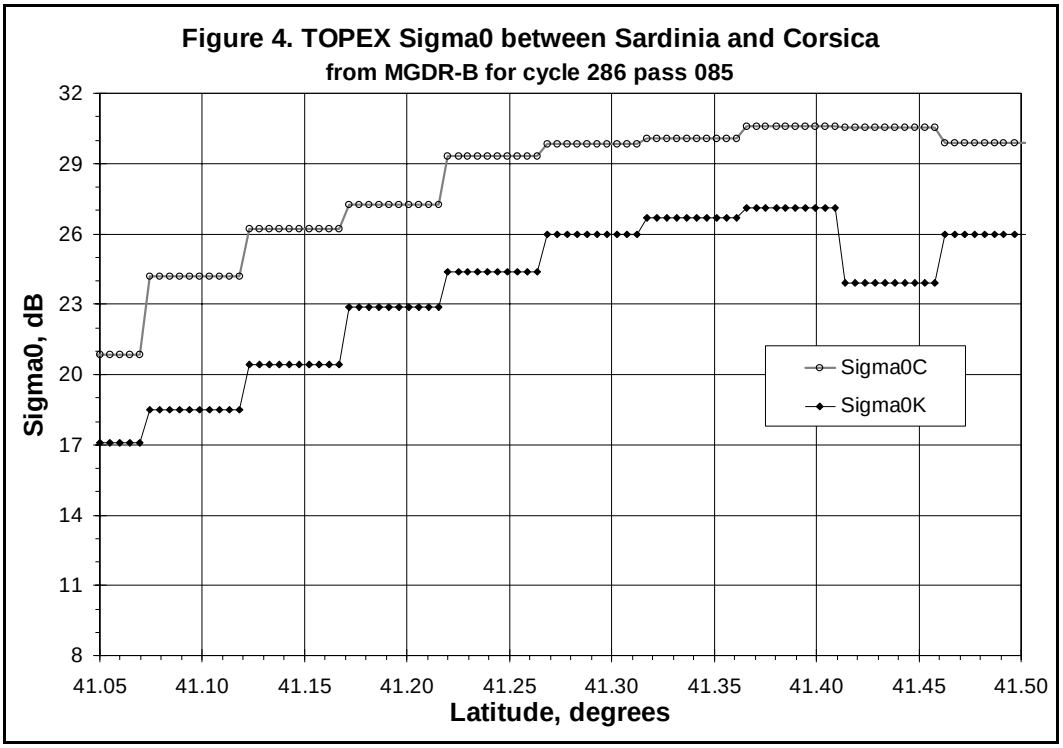
the geophysical effects such as ionospheric electron content and wet and dry troposphere. These corrections should not change the picture greatly, however. The "good" values in Figure 2 are



those for which the LandWater flag indicated non-land, the altimeter was in the correct fine-tracking mode, and the individual high-rate height flags were zero. The solid grey line in this figure is a quartic polynomial which was fitted to about fifteen different cycles pass 085 in this region, and the fit parameters are the five coefficients for the polynomial plus one offset value for each pass used; this provides an approximate local reference for forming fit residuals so that we can see a detrended SSH *vs*. latitude record.

Figure 3 is the cycle 286 plot showing the detrended high-rate SSH residuals, derived from Figure 2, emphasizing the apparent ringing. On this and later plots of SSH residuals, there is an individual point standard deviation calculated for data within the indicated latitude range. The high-rate SSH values will have point to point correlation caused by the TOPEX range tracker, so these standard deviation values will be incorrect because they were calculated assuming completely uncorrelated values.

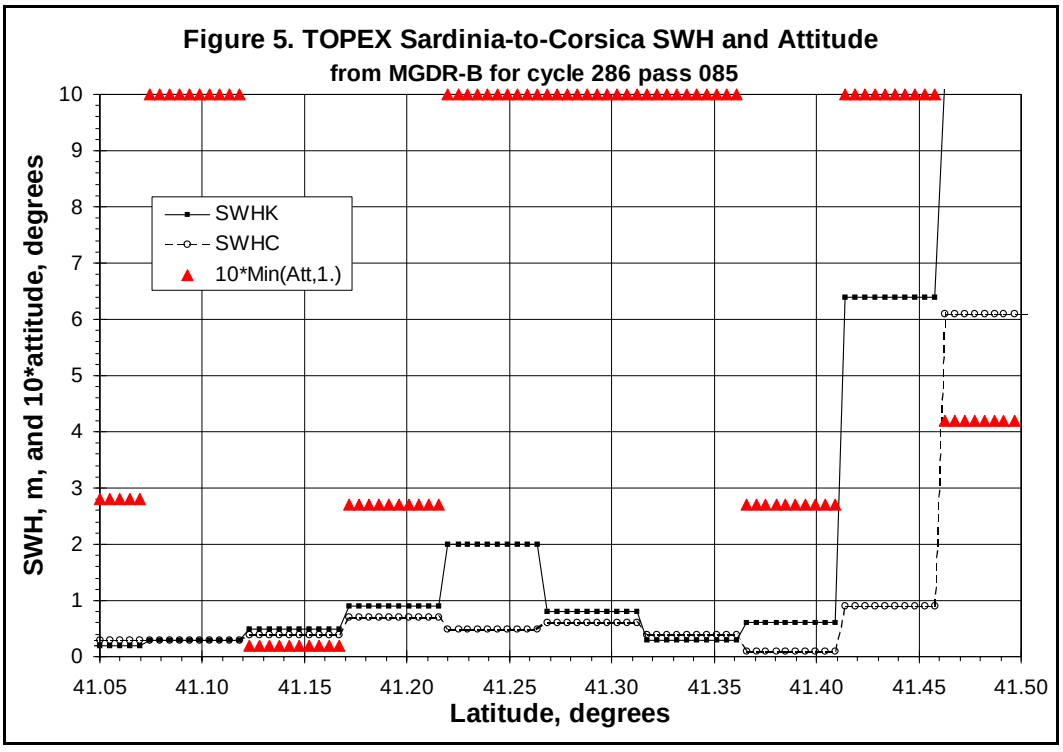
Figures 4 shows the cycle 286 pass 085 sigma0 values plotted *vs*. the same latitude used in Figures 2 and 3. The sigma0 estimates are available only as frame averages, at ~1/second rate, and these per-frame values have simply been replicated ten times to be plotted on the 10/frame latitude scales of Figures 2 and 3. Both Ku- and C-band sigma0 estimates are very high, indicating probable presence of a sigma0 bloom. We have described elsewhere the sigma0 bloom



which is our designation for a ocean region of anomalously high apparent sigma0. The sigma0 blooms can persist for tens of seconds in the TOPEX record. The sigma0 bloom probably

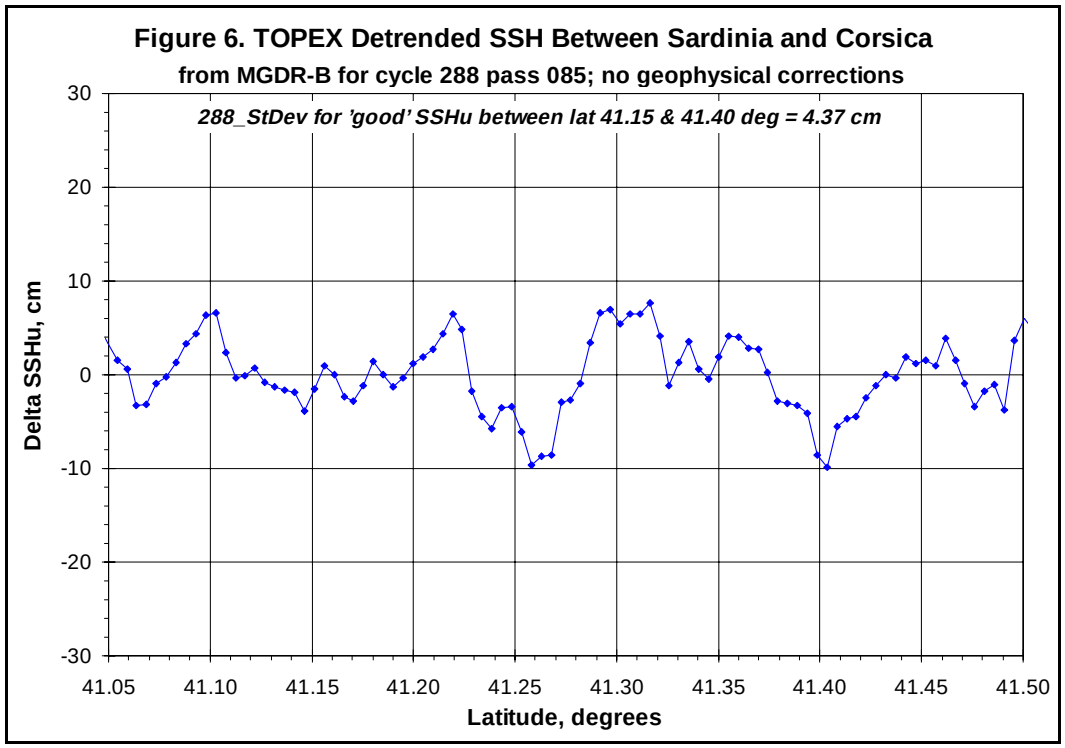
indicates that at least part of the altimeter's return signal came from relatively smooth ocean surface. Sigma0 blooms are more likely to occur in regions of low SWH and low winds; some sigma0 blooms may also be associated with regions having surface slicks. In a sigma0 bloom region the return waveform shapes do not agree with the mean return waveform model on which radar altimeter tracker design is based, and the range values are contaminated at some level. For TOPEX data I have come to believe that any Ku-band overwater value of greater than 14 dB is highly suspicious and probably should be rejected. Figure 4 indicates that **none** of the cycle 286 pass 085 SSH values in this Sardinia to Corsica region are reliable.

Figure 5 plots the SWH and attitude estimates for this pass. The lesser of the attitude or 1.0 degrees has been scaled by a factor of ten, so that any attitude estimate 1.0 degree or greater



would be plotted at the full vertical scale in Figure 5. In general there should be no valid TOPEX attitude estimates of greater than 0.25 degrees or so (except in the attitude bias calibration maneuver, the ABCAL, which is executed for 15 minutes once every half year). The extreme attitude estimates in Figure 5 come from 2.55 degrees in the MGDR-B, and this is a flag of bad attitude rather than a valid estimate. So Figure 5 also indicates that the cycle 286 pass 085 SSH data are unreliable. Only for one frame, around latitude 41.15 degrees, is the estimated attitude less than 0.25, and this is probably not to be trusted either. Both Figures 4 and 5 indicate that the cycle 286 pass 085 is useless for altimeter verification at the Ajaccio, Corsica site.

Figure 6 shows the SSH residual plot in the same latitude region for cycle 288. All of the Ku sigma0 values are less than 14 dB and all of the attitude estimates are less than 0.25 degrees, and the SSH residuals are much better behaved than those in Figure 2. The high-rate data for SSH *vs*. latitude from pass 085 were examined in the Sardinia to Corsica region for TOPEX cycles 270 through 288, a total of 18 TOPEX Side B passes (there was one SSALT cycles within this cycle span), and found that Figure 6 is typical of those regions in which the Ku-band sigma0 was less than 14 dB and the attitude angle was less than 0.25 degrees.



Also the high-rate SSH *vs*. latitude data were examined for TOPEX Side A cycles 100 through 119 in the Sardinia to Corsica region, a total of 17 cycles (there were two SSALT cycles in this cycle span, and one cycle whose data were lost because of a safe hold). Qualitatively the same behavior was observed for Side A and Side B. There were passes in which the Ku sigma0 was greater than 14 dB or the attitude estimates exceeded 0.25 degrees for the entire Sardinia to Corsica span, and Figure 7 is the SSH residual plot for one of these "bad" passes. The ringing is not as extreme as for the Side B cycle 286 pass shown in Figure 3 (cycle 286 pass 085 had the worst looking SSH residual plot of all the 35 passes examined), but Figure 7 indicates that cycle 107 pass 085 would probably not be good to use at the Ajaccio, Corsica vicinity verification site. Figure 8, for cycle 109, shows an example of a "good" Side A pass for which all the Ku sigma0 values were less than 14 dB and all the attitude estimates were less than 0.25 degrees for the latitude range shown.

Figure 7. TOPEX Detrended SSH Between Sardinia and Corsica
from MGDR-B for cycle 107 pass 085; no geophysical corrections

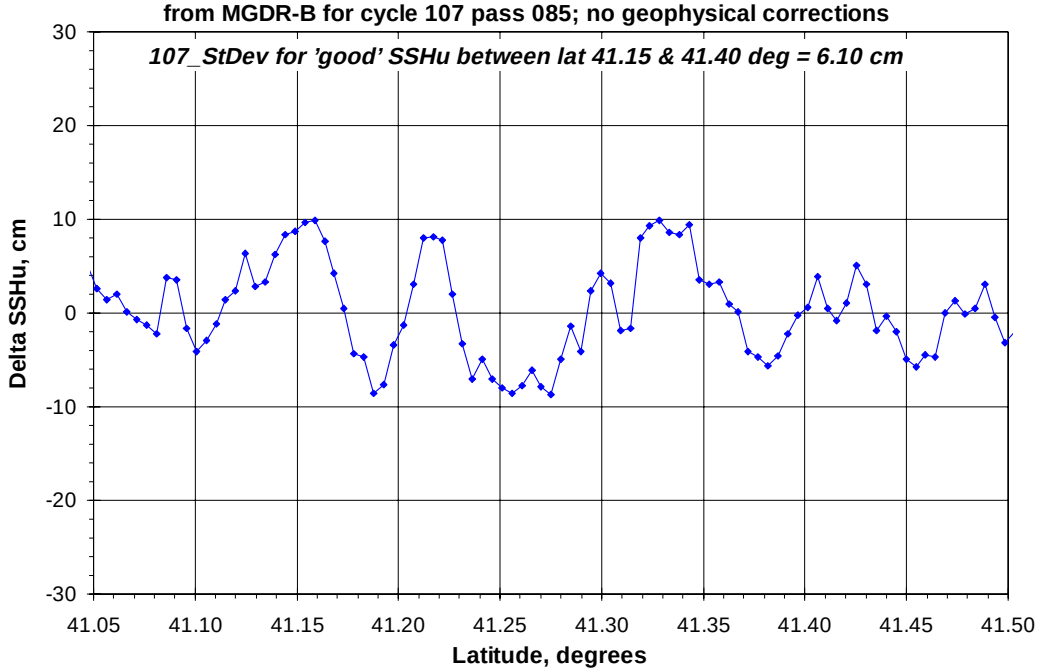
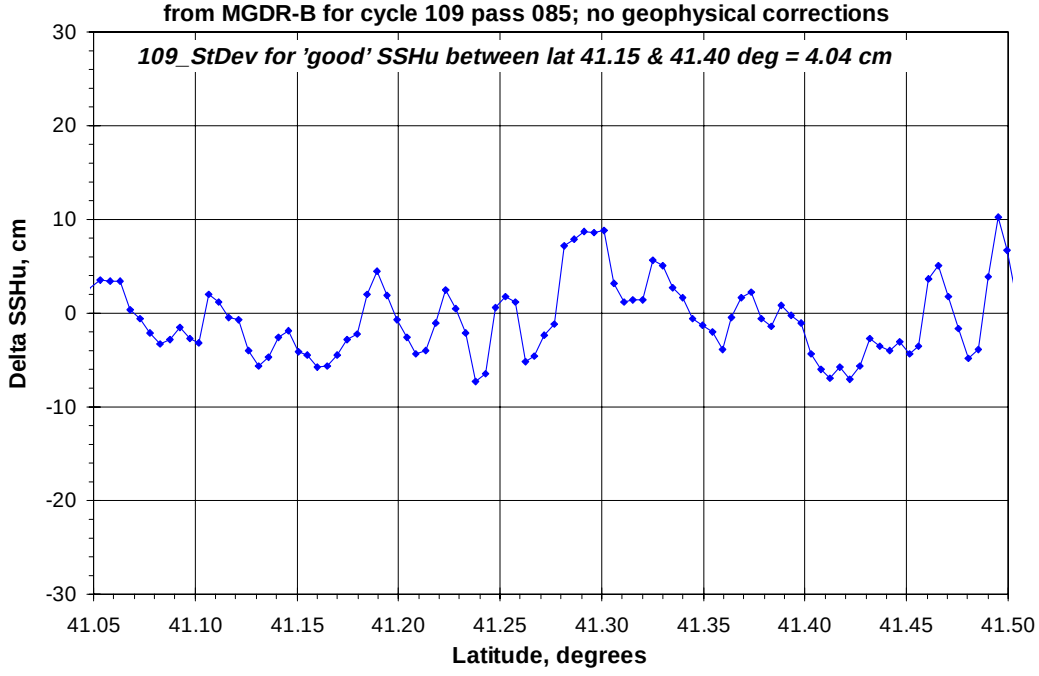


Figure 8. TOPEX Detrended SSH Between Sardinia and Corsica
from MGDR-B for cycle 109 pass 085; no geophysical corrections



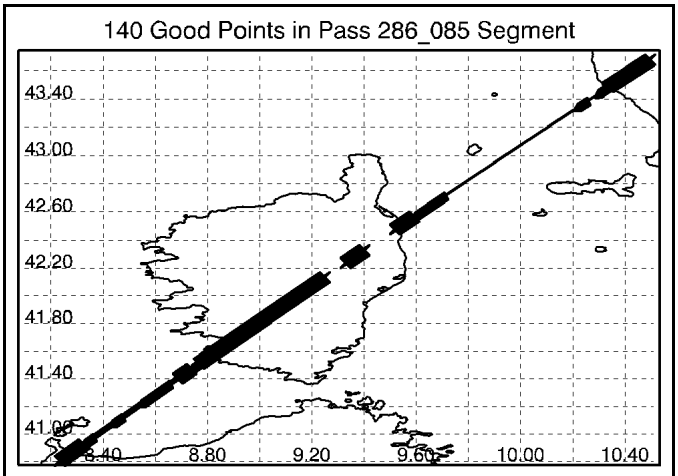


Figure 9. Cycle 286 Pass 085, Sardinia to Italy.

Figure 9, from another IDL procedure, shows the high-rate latitude *vs*. longitude plot for cycle 286 pass 085 coming off Sardinia, traversing Corsica, and going onshore at Italy. This figure used four different plot symbols, but they show up only as different width for the plot reproduced here. The widest symbol indicates data having the wrong mode, or indicated as over land by the LandWater flag, or having non-zero values of the high-rate height flag. These will be referred to as Type 3 data, and the over-Corsica part of the track in Figure 9 shows Type 3 data. Type 2 data are those which are not Type 3 but for which the attitude estimate is greater than 0.3 degrees, and Type 2 examples are seen immediately after the end of the Type 3 data coming off Corsica's northeast corner. Type 1 data are those which are neither Type 3 nor Type 2 but for which the Ku-band sigma0 exceeds 14 dB. Type 1 data have the second narrowest symbols, and examples are seen in the Sardinia to Corsica region of Figure 9 in which there is switching between Type 2 and Type 1. Finally Type 0 data are those which are not Type 3, Type 2, or Type 1, and in Figure 9 the only Type 0 data are in the middle of the Corsica to Italy part of the plot, between latitudes 42.8 and 43.3 degrees.

This hierarchy of data types, 3 to 0, has been chosen for obvious data screening. Nobody would consider using Type 3 SSH data. The Type 2 data indicate attitude estimate anomalies. It's not the actual attitude which is changing but the altimeter's waveform-based estimate of the attitude. The TOPEX attitude estimate is a very sensitive indicator of waveform distortions, probably the result of sigma0 blooms; while one cannot quantitatively predict the SSH errors resulting from waveform changes from sigma0 blooms, it would be inadvisable to use any Type 2 data for verification site purposes. The Type 1 data, indicating excessive apparent Ku-band sigma0, are also unreliable for verification. Only Type 0 data should be used, and in the pass portion shown in Figure 9 there are 140 individual high-rate Type 0 data, a total of 14 frames or approximately 14 seconds.

In Figure 9 there as a small island at approximately 43.03 latitude and 9.84 longitude. That is Capraia at which there has also been TOPEX/Poseidon verification work done. Figure 9 indicates that cycle 286 pass 085 was no good for verification use between Sardinia and Corsica, but should have been good for Capraia verification.

Figure 10 shows the "good points plot", the equivalent of Figure 9, for Side B cycle 288 whose Sardinia to Corsica SSH residuals were plotted in Figure 6. This was one of the good Side B passes for the Ajaccio, Corsica verification site, and Figure 10 indicates that this pass would also have been good for Capraia verification.

Figure 11 shows the good points plot for Side A cycle 107 (whose SSH residuals are shown in Figure 7), and indicates bad performance Sardinia-to-Corsica and mixed performance Corsica-to-Italy.

Similarly Figure 12 shows the good points plot for Side A cycle 109 (whose SSH residuals are shown in Figure 8), and indicates good behavior both in the Sardinia-to-Corsica and the Corsica-to-Italy pass portions.

Table 1 summarizes the number of "good" high-rate SSH values (i.e., Type 0 data) for the 35 different cycles examined in this study. The attitude and Ku sigma0 limits were 0.30 degrees and 14.05 dB, respectively, in producing Figures 9 through 12, and even these limits might be too generous. Limits of 0.20 degrees and 13 dB might have been more conservative. Nevertheless Table 1 gives a rough idea of the amount of data available for Ajaccio, Corsica and the Capraia verification sites. The percentage columns in Table 1 are the number as a percentage of the maximum number seen in the 35 passes examined; the maximum number was 110 (11 frames) for the Sardinia-to-Corsica portion, and 160 (16 frames) in the Corsica-to-Italy portion.

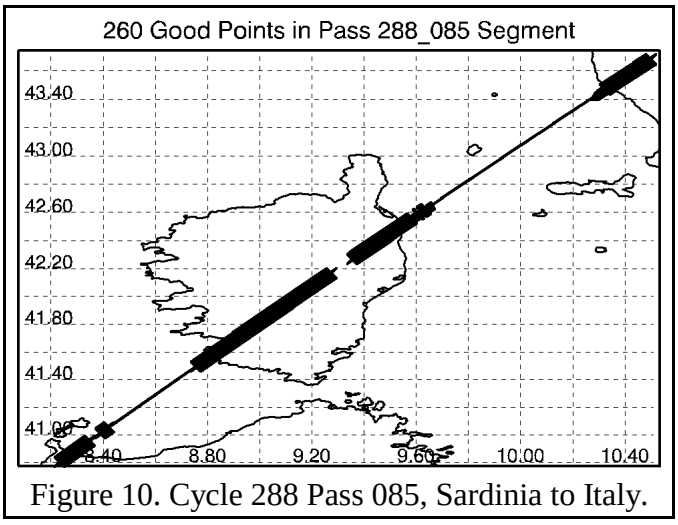


Figure 10. Cycle 288 Pass 085, Sardinia to Italy.

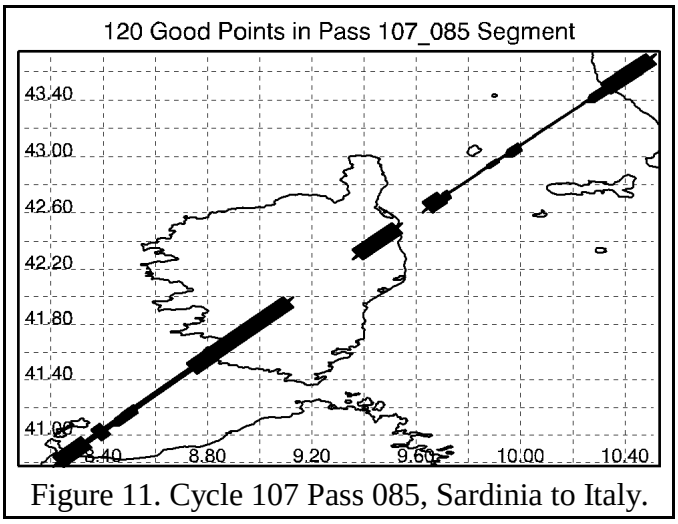


Figure 11. Cycle 107 Pass 085, Sardinia to Italy.

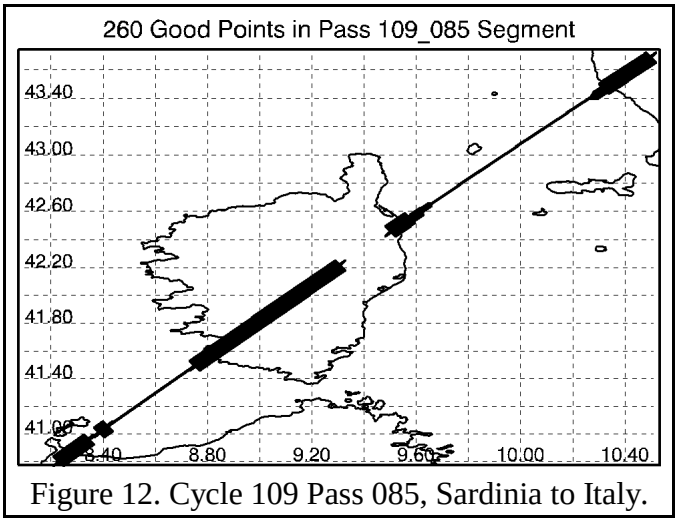


Figure 12. Cycle 109 Pass 085, Sardinia to Italy.

Table 1. Summary of Number of Good High-Rate SSH Values in Sardinia-to-Corsica and Corsica-to-Italy Portions of Pass 085 in TOPEX Cycles.

		Sardinia-to-Corsica		***Corsica-to-Italy***	
TOPEX Side	**Cycle_ Pass**	**Number of "Good" SSH Values**	**Percent Good**	**Number of "Good" SSH Values**	**Percent Good**
Side A	100_085	40	36%	0	0%
Side A	101_085	20	18%	90	56%
Side A	102_085	80	73%	30	19%
Side A	104_085	30	27%	10	6%
Side A	105_085	50	45%	20	13%
Side A	106_085	90	82%	140	88%
Side A	107_085	0	0%	120	75%
Side A	108_085	100	91%	0	0%
Side A	109_085	100	91%	160	100%
Side A	110_085	90	82%	120	75%
Side A	111_085	90	82%	80	50%
Side A	112_085	70	64%	120	75%
Side A	113_085	100	91%	0	0%
Side A	115_085	60	55%	60	38%
Side A	116_085	80	73%	120	75%
Side A	117_085	98	89%	100	63%
Side A	119_085	100	91%	80	50%
Side B	270_085	50	45%	108	68%
Side B	271_085	110	100%	150	94%
Side B	272_085	90	82%	50	31%
Side B	273_085	30	27%	0	0%
Side B	274_085	0	0%	60	38%
Side B	275_085	70	64%	150	94%
Side B	276_085	80	73%	140	88%
Side B	277_085	50	45%	150	94%
Side B	279_085	0	0%	150	94%
Side B	280_085	90	82%	140	88%
Side B	281_085	0	0%	0	0%
Side B	282_085	100	91%	20	13%
Side B	283_085	90	82%	90	56%
Side B	284_085	80	73%	40	25%
Side B	285_085	50	45%	0	0%
Side B	286_085	0	0%	140	88%
Side B	287_085	80	73%	140	88%
Side B	288_085	100	91%	160	100%

From Table 1 one can get an appreciation of how difficult it is to get good verification passes for a site not in open ocean. The main problem is the sigma0 bloom possibility. We know that upwards of 5% of the TOPEX over-ocean data are possibly contaminated by the sigma0 bloom, but these bloom distributions vary greatly, both geographically and temporally, and there are regions and seasons in which 50% of the over-ocean data can be contaminated. The Sardinia to Corsica region has relatively shallow water and the possibility of shielding from wind on three sides, and it is not surprising that it is difficult to get good uncontaminated high-rate SSH data for this site. Table 1 also indicates that a Capraia site would have similar difficulties.

A very brief characterization of Table 1 is that in the Sardinia-to-Corsica region a Side A pass's good SSH data would be 64% ±29% of the maximum available and the Side B pass's good data would be 54% ±35% of the maximum available. In the Corsica-to-Italy region a Side A pass's good SSH data would be 46% ±34% of the maximum available and the Side B pass's good data would be 59% ±38% of the maximum available. These are relatively large standard deviations, and would lead to relatively large frustration on the part of anyone doing altimeter verification in this region.

To summarize this section, for the nearly three dozen passes examined, no striking differences were found between the Side A and Side B high-rate SSH performance. The particular example of cycle 286 pass 085 is the worst of all the passes examined, and is clearly affected by a sigma0 bloom. Additional editing criteria have been proposed to reject bloom-contaminated data, and for the Sardinia-to-Corsica and Corsica-to-Italy over-water regions we have showed how much data were probably good in each of the passes examined.

Harvest Platform Vicinity TOPEX Verification Passes

After our examination of TOPEX high-rate (10 per frame) sea surface height (SSH) data in the vicinity of the Corsica and the Capraia verification sites west of Italy, it was interesting to look at the high-rate SSH data for the Harvest platform off the California coast. The Corsica-Capraia sites were in the ground track of pass 085, and the Harvest site is in the pass 043 ground track. For quick comparison, pass 043 was used from the same 35 TOPEX cycles for which we had studied pass 085, and MGDR-B data were again used. It was expected that the Harvest platform would have a higher fraction of good passes because the altimeter approaches the platform from over open ocean, whereas the Sardinia-to-Corsica passes come off land at Sardinia and traverse relatively shallow and protected water before going back overland at Corsica. In brief summary, there were fewer problem passes at Harvest than at Corsica.

Figure 13 shows the ground track of a pass 043 which comes from the southwest over open ocean and crosses the California coastline. In this figure a 10 km radius footprint is shown centered at the Harvest platform. Three different plot symbols plot the frame latitude *vs*. longitude, approximately 1 second per point. The symbols are chosen according to the value of the TOPEX LandWater flag which is derived from Geo_Bad_1 in the MGDR-B record. The smallest symbol indicates deep ocean, and the intermediate symbol indicates shallow water. Then the largest plot symbol, the "X", indicates land. In TOPEX GDR (and MGDR-B) the land boundary has been extended out by 10 km or so from actual landfall because of the radiometer's large footprint. In Figure 13, first there are 39 frames over deep water, then 6 frames of shallow water ending at about the Harvest platform position, and finally the last 14 frames are over land.

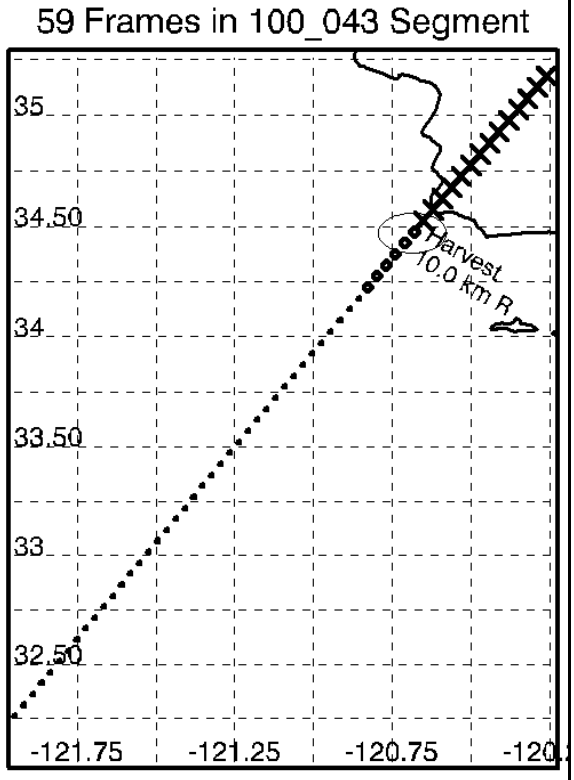


Figure 13. TOPEX Ground Track Crossing Harvest Platform.

Figure 14 shows an example of a problem Harvest pass. This plots the high-rate latitudes *vs*. longitudes on a magnified scale compared to Figure 13, and the Figure 14 footprint oval is for a 3 km radius. The segment length in Figure 14 was chosen to give about the same over-water distance as in the Sardinia-to-Corsica pass 085. Figure 14 uses the same four plot symbols as in our Corsica region work. The widest symbol indicates Type 3 data, those having the wrong mode or having non-zero values of the high-rate height flag (a small difference from the Corsica work is that the LandWater flag was not used, because that would have eliminated all the points between the Harvest platform and the

California coast). The over-California part of the track in Figure 14 shows Type 3 data. Type 2 data are those which are not Type 3 but for which the attitude estimate is greater than 0.3 degrees, and Type 2 examples are seen in the first part of the pass segment in the lower left part of Figure 14. Type 1 data are those which are neither Type 3 nor Type 2 but for which the Ku-band sigma0 exceeds 14 dB. Type 1 data have the second narrowest symbols, and in Figure 14 we see switching between Type 2 and Type 1 in the first half (the lower left part) of the pass segment. Finally Type 0 data are those which are not Type 3, Type 2, or Type 1, and in Figure 14 the only Type 0 data are the ten values just before the 3 km footprint outline. The data switch to Type 1 crossing the Harvest 3km radius footprint, then there are some Type 2 data between Harvest and the coast, and after landfall the data become Type 3.

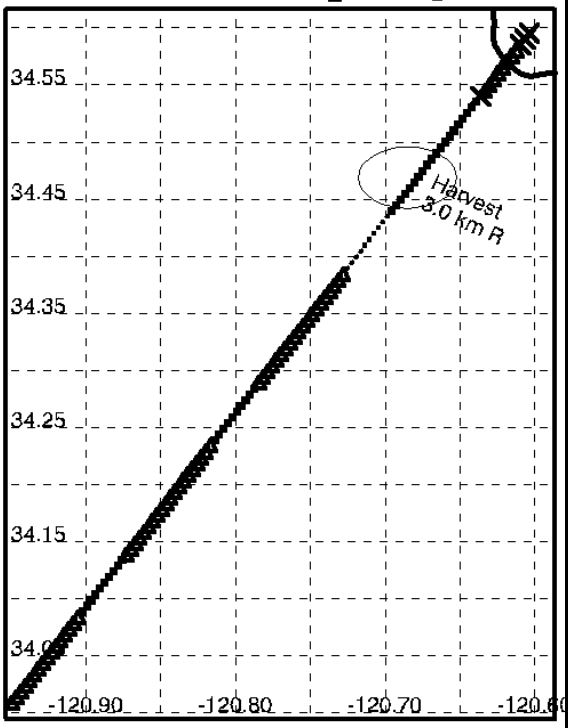


Figure 14. TOPEX Cycle 286 Pass 043 Crossing Harvest Platform.

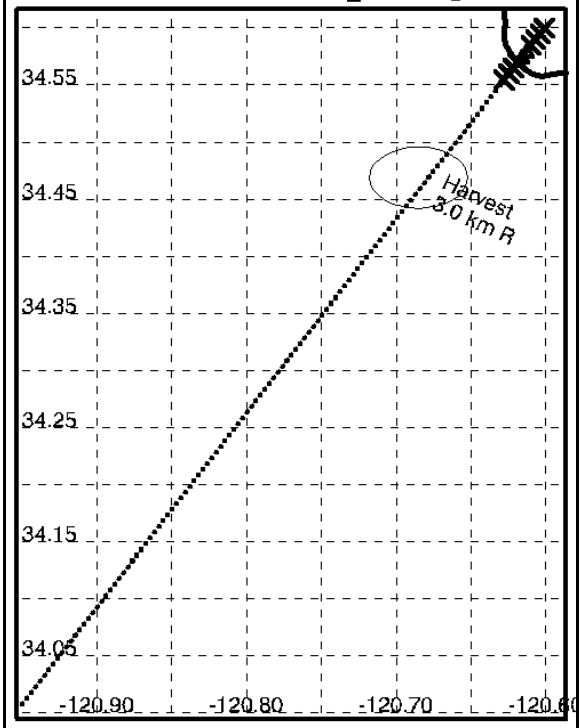


Figure 15. TOPEX Cycle 288 Pass 043 Crossing Harvest Platform.

By contrast, cycle 288 pass 043 is one of the good Harvest passes, and Figure 15 shows this pass whose data are all good until landfall.

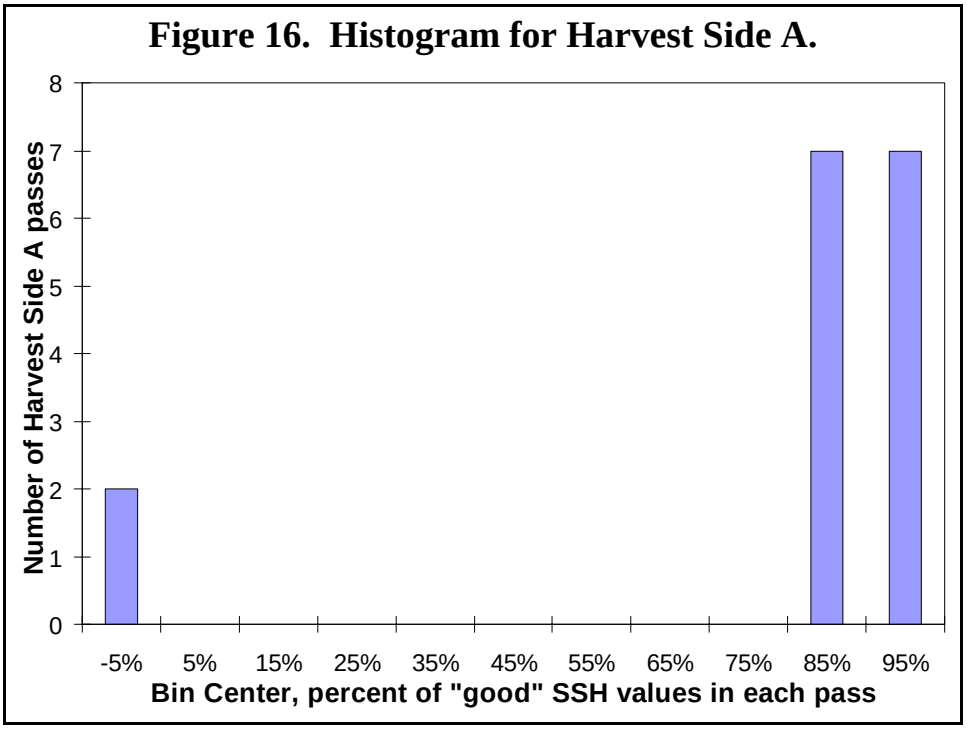
Plots like Figure 14 were generated for all 35 cycles of pass 043, and Table 2 summarizes the results. This looks better than Table 1 from the Corsica study; only four of the passes in the Harvest Table 2 have less than 80% of the maximum possible number of good SSH values.

Table 2. Summary of Number of Good High-Rate SSH Values in Harvest Region of Pass 043 in TOPEX Cycles.

TOPEX Side	Cycle_ Pass	Number "Good" SSH Values	Percent Good		TOPEX Side	Cycle_ Pass	Number "Good" SSH Values	Percent Good
Side A	100_043	97	89%		Side B	270_043	96	88%
Side A	101_043	106	97%		Side B	271_043	82	75%
Side A	102_043	105	96%		Side B	272_043	92	84%
Side A	104_043	92	84%		Side B	273_043	92	84%
Side A	105_043	88	81%		Side B	274_043	100	92%
Side A	106_043	99	91%		Side B	275_043	94	86%
Side A	107_043	99	91%		Side B	276_043	92	84%
Side A	108_043	102	94%		Side B	277_043	99	91%
Side A	109_043	105	96%		Side B	279_043	97	89%
Side A	110_043	95	87%		Side B	280_043	99	91%
Side A	111_043	0	0%		Side B	281_043	105	96%
Side A	112_043	93	85%		Side B	282_043	95	87%
Side A	113_043	97	89%		Side B	283_043	93	85%
Side A	115_043	0	0%		Side B	284_043	102	94%
Side A	116_043	102	94%		Side B	285_043	99	91%
Side A	117_043	95	87%		Side B	286_043	10	9%
Side A	119_043	93	85%		Side B	287_043	107	98%
					Side B	288_043	109	100%

Figures 16 and 17 show histograms of the Harvest region Table 2 “Percent Good” columns, for Side A and Side B, respectively. Then Figures 18 and 19 show the corresponding “Percent Good” histograms for the Sardinia-to-Corsica pass 085 Side A and Side B, respectively. The

Figure 16. Histogram for Harvest Side A.



histograms are for 10% bins, and the labels indicate bin center, so the rightmost bin is from 90 to 100% of the maximum number of good values. The passes with **no** good values appear in the bin labeled -5%. These histograms clearly indicate the advantage of the Harvest site for Topex verification, compared to the Corsica site.

Figure 17. Histogram for Harvest Side B.

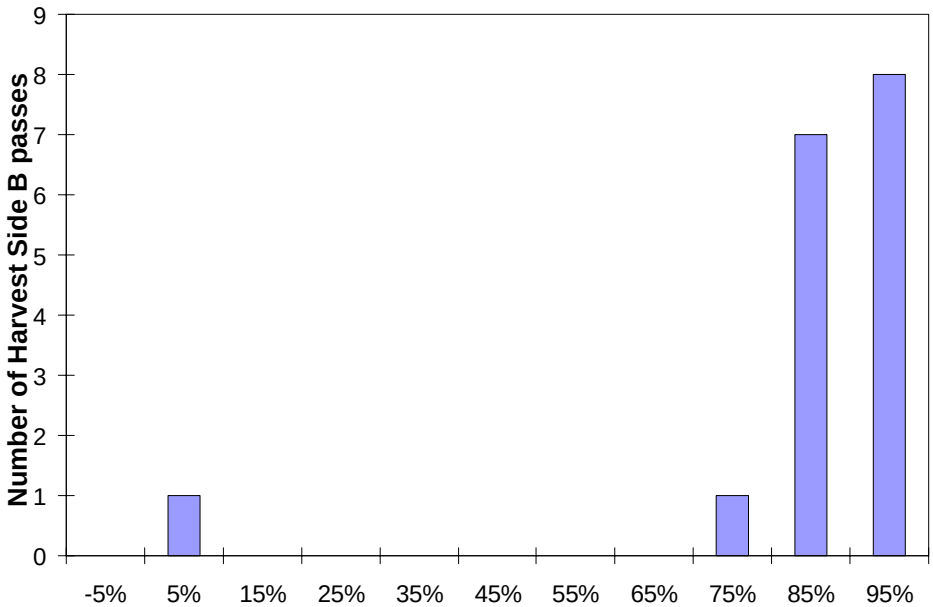
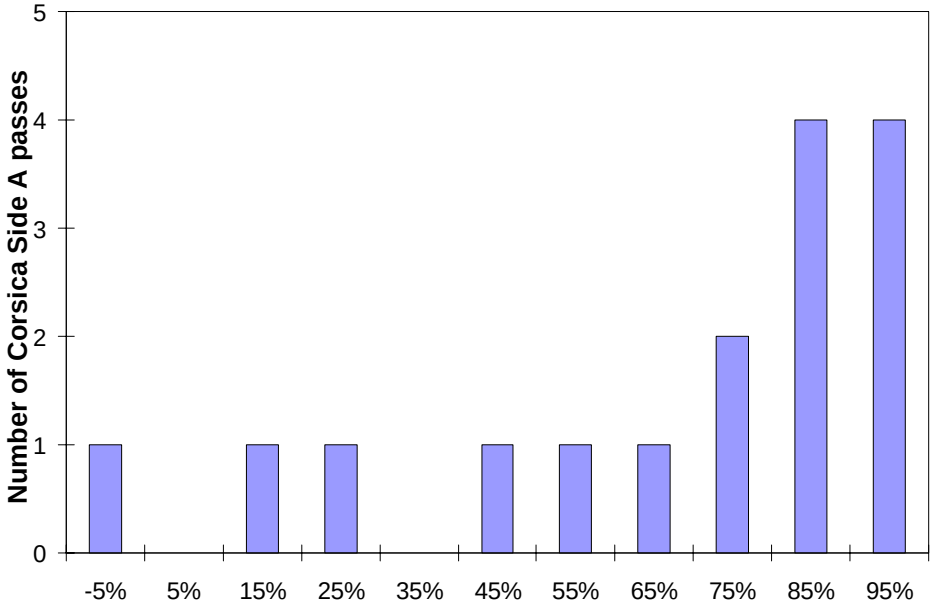


Figure 18. Histogram for Corsica Side A.



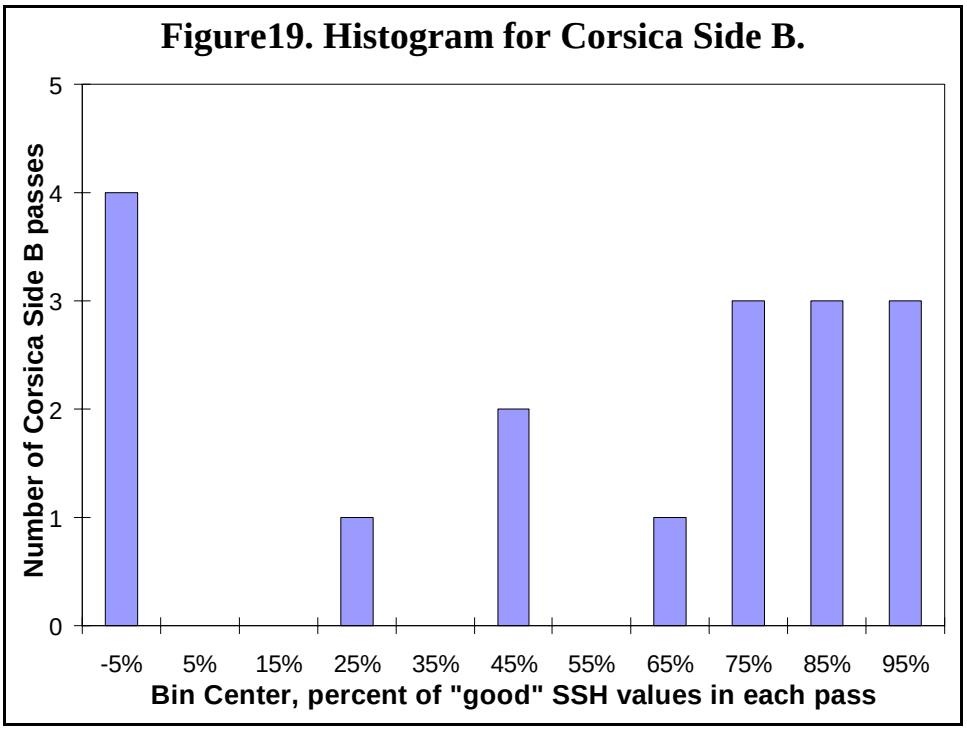


Figure19. Histogram for Corsica Side B.
Number of Corsica Side B passes
0
1
2
3
4
5
-5%
5%
15%
25%
35%
45%
55%
65%
75%
85%
95%
Bin Center, percent of "good" SSH values in each pass